Predictive Tracking Control of Network-based Agent with Communication Delays

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Abstract—**This paper investigates remote tracking control problem of Network-based Agent with communication delays exist in both forward and feedback communication channels. A networked predictive tracking controller is proposed to compensate the negative effects caused by bilateral time-delays in a wireless network. Further more, the problem of consecutive data loss in the feedback channel is solved using aforementioned controller, where lateral movement perturbations are joined. Simulations and experiments are provided in several cases, which verify the realizability and effectiveness of the proposed controller.**

Index Terms—**Networked predictive control, Network-based Agent, remote tracking, time-delay, consecutive data loss.**

I. Introduction

TELEROBOTIC system, which is controlled through a computer network, has become a popular research topic in recent years due to its potential applications in our daily life [1]. In summary, these applications contain unmanned aerial vehicles [2], [3], autonomous underwater vehicles [4], and wheeled mobile robots [5], [6], [7].

Whereas, when the communication network is introduced into the control loop of a traditional control system, the design process and stability analysis of the system change, which transforms the traditional control system into a networked control system. The network-induced delay and data packet dropouts in a networked control system will affect the performance of the system and may even make the system unstable [8]. Several researchers have made efforts to cope with the time-delay and data loss problem in control loop of networked control system [9], [10], [11], [12], [13], [14].

In this paper, the remote tracking control problem of a network-based Agent is considered. Some closely related and relevant literatures are shown in follows. In [15], [16], a joystick is used to control the remote mobile robot, and the motion of joystick is translated into desired linear and angular velocities of mobile robot. In [17], a sliding mode approach is proposed to solve the path tracking problem, where an exact discrete time model of mobile robot is developed as a time-delay system. Authors in [18] solve the problem of discrete time tracking control of an omnidirectional mobile robot through extending the continuous time-delay system to a discrete-time model which is free of delay, and the feedback linearization strategy is adopted to obtain the control inputs. In [19], [20], vehicle active suspension control problem is considered under situation of actuator input delay. In [21], a PD-like controller is applied to the delayed bilateral teleoperation of wheeled robots with force feedback in face of asymmetric and varying-time delays. In [5], [7], [22], predictors are designed to compensate the negative effects of time-delay. Especially in [7], a predictor-controller combination with a remote tracking controller is proposed, and the performance of which is demonstrated using an interconnected robotic platform located partly in Eindhoven, the Netherlands, and Tokyo, Japan.

To the best of authors knowledge, this is the first time a remote tracking control problem is solved using networked predictive control scheme. Inspired by [7], this paper adopt a similar tracking controller in discrete-time domain. Following that, a networked predictive control scheme was designed to compensate the negative effects caused by communication delays and data losses.

The contribution of the current paper is proposed a remote tracking controller based on networked predictive control strategy, and it is capable of compensating for bilateral time-delays in a wireless network. It is worth noting that the simulation and experimental results are consistent.

The remainder of this paper is organized as follows. Section II formulates the problem to be solved. In Section III, the networked predictive tracking controller is proposed. Simulation and experimental results are presented in Section IV. Finally, this paper concludes in Section V.

II. Problem formulation

The network-based Agent considered in this paper is a wheeled mobile robot, whose discrete-time model can be described as

$$\begin{bmatrix} x(k+1) \\ y(k+1) \\ \theta(k+1) \end{bmatrix} = \begin{bmatrix} x(k) \\ y(k) \\ \theta(k) \end{bmatrix} + \begin{bmatrix} Tcos\theta(k) & 0 \\ Tsin\theta(k) & 0 \\ 0 & T \end{bmatrix} \begin{bmatrix} \upsilon(k) \\ \omega(k) \end{bmatrix} \tag{1}$$

where $q(k) \triangleq [x(k), y(k), \theta(k)]^T$ is defined as state of mobile robot, $[x(k), y(k)]$ represent the coordinates of mobile robot in global coordinate frame, $\theta(k)$ denotes the angle between moving direction of mobile robot and X^+ axis of global coordinate frame, respectively. $\upsilon(k)$ and $\omega(k)$ are control inputs of the system, which are also linear and angular velocities of the mobile robot. T is discrete sample time with $0 < T < 1s$.

Supposing that the reference state to be tracked satisfy (1), which behaves as a virtual mobile robot with its state defined

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by $q_r(k) \triangleq [x_r(k), y_r(k), \theta_r(k)]^T$. The positional relationship between reference and real mobile robot is shown in Fig. 1.

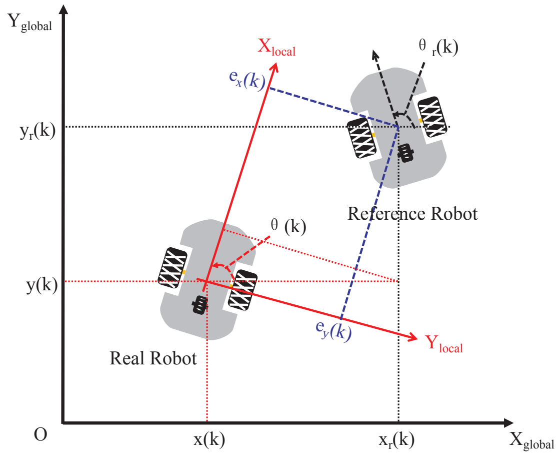


Fig. 1. Positional relationship between reference robot and real robot

The state deviation can be derived as

$$\begin{bmatrix} e_x(k) \\ e_y(k) \\ e_\theta(k) \end{bmatrix} = R(k) * \begin{bmatrix} x_r(k) - x(k) \\ y_r(k) - y(k) \\ \theta_r(k) - \theta(k) \end{bmatrix} \tag{2}$$

which is mapped into local coordinate frame of real mobile robot, with

$$R(k) = \begin{bmatrix} cos\theta(k) & sin\theta(k) & 0 \\ -sin\theta(k) & cos\theta(k) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Further more, it have

$$\begin{bmatrix} e_x(k+1) \\ e_y(k+1) \\ e_\theta(k+1) \end{bmatrix} = \begin{bmatrix} 1 & T\omega(k) & 0 \\ -T\omega(k) & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} e_x(k) \\ e_y(k) \\ e_\theta(k) \end{bmatrix} + T \begin{bmatrix} \upsilon_r(k) cose_\theta(k) - \upsilon(k) \\ \upsilon_r(k) sine_\theta(k) \\ \omega_r(k) - \omega(k) \end{bmatrix} \tag{3}$$

with $\upsilon_r(k)$ and $\omega_r(k)$ are linear and angular velocities of reference robot, respectively. To solve the tracking control problem shown in (3), one have to design proper controller to eliminate the state errors, that is, $q(k) \to q_r(k)$ as $k \to \infty$. A tracking controller, which was proposed and examined in [7], in discrete time domain is chosen here. The discrete-time form of this tracking controller is

$$\begin{bmatrix} \upsilon(k) \\ \omega(k) \end{bmatrix} = \begin{bmatrix} \upsilon_r(k) \\ \omega_r(k) \end{bmatrix} + \begin{bmatrix} k_x & -k_y\omega_r(k) & 0 \\ 0 & 0 & k_\theta \end{bmatrix} \begin{bmatrix} e_x(k) \\ e_y(k) \\ e_\theta(k) \end{bmatrix} \tag{4}$$

where k_x, k_y and k_θ are positive control parameters, $\upsilon_r(k)$, $\omega_r(k)$ are reference inputs, and $u(k) = [\upsilon(k)\ \omega(k)]^T$ are control inputs of mobile robot. Substituting (4) into (3), it gives

$$\begin{cases} \begin{bmatrix} e_x(k+1) \\ e_y(k+1) \end{bmatrix} = A(k) \begin{bmatrix} e_x(k) \\ e_y(k) \end{bmatrix} + G(k) e_\theta(k) & \text{(5a)} \\ e_\theta(k+1) = (1 - Tk_\theta) e_\theta(k) & \text{(5b)} \end{cases}$$

with

$$A(k) = \begin{bmatrix} 1 - Tk_x & T\omega_r(k)(1 + k_y) \\ -T\omega_r(k) & 1 \end{bmatrix}$$

$$G(k) = \begin{bmatrix} k_\theta e_y(k) + \upsilon_r(k) \frac{cose_\theta(k) - 1}{e_\theta(k)} \\ -k_\theta e_x(k) + \upsilon_r(k) \frac{sine_\theta(k)}{e_\theta(k)} \end{bmatrix} T$$

With tracking controller (4) and methods proposed in [23], the closed-loop state error system (5) can be proved to be uniformly globally asymptotically stable (UGAS). When the communication network is introduced into the control loop, especially when network-induced delay exists in the communication channel, the design process of the controller and stability analysis of the system change, which transform the traditional control system into a networked control system.

In the current problem setting, the mobile robot subjects to network-induced bilateral time-delays consisting of a forward and a backward time-delay(see Fig. 2).

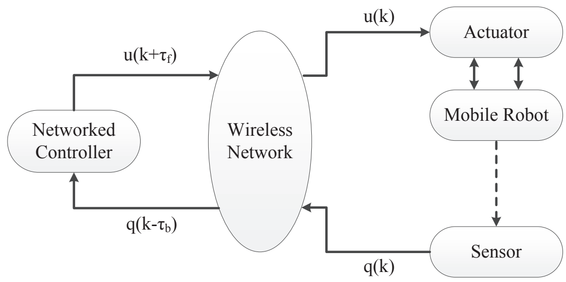


Fig. 2. Schematic of remote tracking control

In Fig. 2, constant time-delay τ_b and τ_f exist in the feedback and forward communication channels respectively, where $\tau_b, \tau_f \in (0, \tau_{max})$, and it is assumed that τ_{max} is upper bound of time-delay in each channel. While using tracking controller (4), the overshoot of the system increases as the network delay goes up, but the moving trajectory will finally converge to the reference states due to $q_r(k) - q(k - \tau_b)$. Whereas, when τ_b and τ_f are big enough, the moving trajectory cannot converge to the reference states anymore.

To cope with this problem, which also is the control goal of this paper, the state $\hat{q}(k + \tau_f | k - \tau_b)$ and control inputs $\hat{u}(k + \tau_f | k - \tau_b)$ of mobile robot should be predicted based on delayed state $q(k - \tau_b)$ to compensate the time-delay τ_b in the feedback channel and τ_f in the forward channel. And this implies that $\hat{q}(k + \tau_f | k - \tau_b) \to q_r(k + \tau_f)$ as $k \to \infty$.

III. Networked Predictive Tracking Controller

As aforementioned in section II, there exist constant time-delay τ_b and τ_f, respectively, in the feedback and forward channel. In networked controller side at stepping time k, the delayed state $q(k - \tau_b)$ of mobile robot is received, and control inputs $\hat{u}(k + \tau_f | k - \tau_b)$ will be sent to mobile robot simultaneously, then the remote tracking problem can be solved.

It should be noted that the future reference states $\hat{q}_r(k + m|k)$, for $m \in (1, \tau_f)$, are used when estimating future control inputs of mobile robot. Based on historical states of

$q_r(k)$ and reference inputs $\upsilon_r(k)$, $\omega_r(k)$, the future reference states can be estimated. To compact the notation, in the sequel it will use $\psi_k/\psi_{*,k} = \psi(k)/\psi_*(k)$ for short, where $\psi/\psi_* \in (q, q_r, \upsilon_r, \upsilon, \omega_r, \omega, e_x, e_y, e_\theta)$. If there are no internal and external uncertainties in (1), the following result is derived on the stability of the closed-loop predictive control system.

Theorem 1. *Consider the discrete-time kinematics model of mobile robot (1) with constant time-delays τ_b and τ_f exist in feedback and forward communication channels, respectively, of the control loop, where $\tau_b, \tau_f \in (0, \tau_{max})$, if networked predictive controller $\hat{u}(k+\tau_f|k-\tau_b)$ is sent to mobile robot at stepping time k, then the bilateral time-delays in control loop can be compensated actively, and the stability performance of the closed-loop predictive control system is equivalent to that of (5).*

Proof: At stepping time k, the delayed state $q_{k-\tau_b}$ of mobile robot is received, it gives

$$\begin{bmatrix} e_{x,k-\tau_b} \\ e_{y,k-\tau_b} \\ e_{\theta,k-\tau_b} \end{bmatrix} = R_{k-\tau_b} * \begin{bmatrix} x_{r,k-\tau_b} - x_{k-\tau_b} \\ y_{r,k-\tau_b} - y_{k-\tau_b} \\ \theta_{r,k-\tau_b} - \theta_{k-\tau_b} \end{bmatrix} \tag{6}$$

with

$$R_{k-\tau_b} = \begin{bmatrix} cos\theta_{k-\tau_b} & sin\theta_{k-\tau_b} & 0 \\ -sin\theta_{k-\tau_b} & cos\theta_{k-\tau_b} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Substitute state deviation (6) into controller (4), which gives $u_{k-\tau_b}$.

Iteration step 1: Using system model (1), $u_{k-\tau_b}$ and state deviation (6), it can be derived that

$$\begin{bmatrix} \hat{e}_{x,k-\tau_b+1|k-\tau_b} \\ \hat{e}_{y,k-\tau_b+1|k-\tau_b} \end{bmatrix} = A_{k-\tau_b} \begin{bmatrix} e_{x,k-\tau_b} \\ e_{y,k-\tau_b} \end{bmatrix} + G_{k-\tau_b} e_{\theta,k-\tau_b}$$
$$\hat{e}_{\theta,k-\tau_b+1|k-\tau_b} = (1 - Tk_\theta) e_{\theta,k-\tau_b}$$

where

$$A_{k-\tau_b} = \begin{bmatrix} 1 - Tk_x & T\omega_{r,k-\tau_b}(1 + k_y) \\ -T\omega_{r,k-\tau_b} & 1 \end{bmatrix}$$
$$G_{k-\tau_b} = \begin{bmatrix} k_\theta e_{y,k-\tau_b} + \upsilon_{r,k-\tau_b} \frac{cose_{\theta,k-\tau_b} - 1}{e_{\theta,k-\tau_b}} \\ -k_\theta e_{x,k-\tau_b} + \upsilon_{r,k-\tau_b} \frac{sine_{\theta,k-\tau_b}}{e_{\theta,k-\tau_b}} \end{bmatrix} T$$

then the control inputs are calculated as $\hat{u}_{k-\tau_b+1|k-\tau_b}$.

Iteration step s: For $s \in [2, \tau_b + \tau_f)$, similarly it have

$$\begin{bmatrix} \hat{e}_{x,k-\tau_b+s|k-\tau_b} \\ \hat{e}_{y,k-\tau_b+s|k-\tau_b} \end{bmatrix} = A_{k-\tau_b+s-1} \begin{bmatrix} \hat{e}_{x,k-\tau_b+s-1|k-\tau_b} \\ \hat{e}_{y,k-\tau_b+s-1|k-\tau_b} \end{bmatrix} + \hat{G}_{k-\tau_b+s-1|k-\tau_b} \hat{e}_{\theta,k-\tau_b+s-1|k-\tau_b}$$
$$\hat{e}_{\theta,k-\tau_b+s|k-\tau_b} = (1 - Tk_\theta) \hat{e}_{\theta,k-\tau_b+s-1|k-\tau_b}$$

the controller is designed as $\hat{u}_{k-\tau_b+s|k-\tau_b}$.

Iteration step $\tau_b + \tau_f$: It gives

$$\begin{bmatrix} \hat{e}_{x,k+\tau_f|k-\tau_b} \\ \hat{e}_{y,k+\tau_f|k-\tau_b} \end{bmatrix} = A_{k+\tau_f-1} \begin{bmatrix} \hat{e}_{x,k+\tau_f-1|k-\tau_b} \\ \hat{e}_{y,k+\tau_f-1|k-\tau_b} \end{bmatrix} + \hat{G}_{k+\tau_f-1|k-\tau_b} \hat{e}_{\theta,k+\tau_f-1|k-\tau_b}$$
$$\hat{e}_{\theta,k+\tau_f|k-\tau_b} = (1 - Tk_\theta) \hat{e}_{\theta,k+\tau_f-1|k-\tau_b}$$

After iterations for $\tau_b + \tau_f$ steps, the networked predictive tracking controller is obtained as $\hat{u}_{k+\tau_f|k-\tau_b}$. Replacing $k+\tau_f$ by $k+1$ in above result, the closed-loop state error system could be described with the following form

$$\begin{cases} \begin{bmatrix} \hat{e}_{x,k+1} \\ \hat{e}_{y,k+1} \end{bmatrix} = A_k \begin{bmatrix} \hat{e}_{x,k} \\ \hat{e}_{y,k} \end{bmatrix} + \hat{G}_k \hat{e}_{\theta,k} & \text{(7a)} \\ \hat{e}_{\theta,k+1} = (1 - Tk_\theta) \hat{e}_{\theta,k} & \text{(7b)} \end{cases}$$

with

$$A_k = \begin{bmatrix} 1 - Tk_x & T\omega_{r,k}(1 + k_y) \\ -T\omega_{r,k} & 1 \end{bmatrix}$$
$$\hat{G}_k = T \begin{bmatrix} k_\theta \hat{e}_{y,k} + \upsilon_{r,k} \frac{cos\hat{e}_{\theta,k} - 1}{\hat{e}_{\theta,k}} \\ -k_\theta \hat{e}_{x,k} + \upsilon_{r,k} \frac{sin\hat{e}_{\theta,k}}{\hat{e}_{\theta,k}} \end{bmatrix}$$

Since it is assumed that there are no internal and external uncertainties in the system, we can conclude that $\hat{q}_{k|k-\tau_b} = q_k$, which yields $\hat{e}_{\sigma,k} = e_{\sigma,k}$, for $\sigma = (x, y, \theta)$. And the predictive tracking controller at mobile robot side could be described as

$$u_k = \hat{u}_{k|k-\tau_f-\tau_b} \tag{8}$$

We see that the closed-loop state error system in (7) is exactly the same as (5), which implies that the stability performance of (7) is equivalent to that of (5), and then the proof is completed. ■

IV. Simulations and Experiments

In this section, the experimental platform is introduced firstly, then some simulation and experimental results, obtained using the same parameters, are provided to demonstrate the control performance of the proposed networked predictive tracking controller.

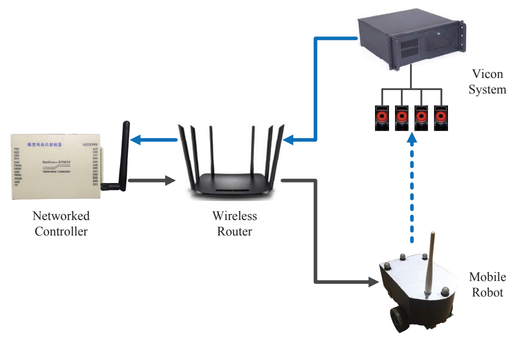
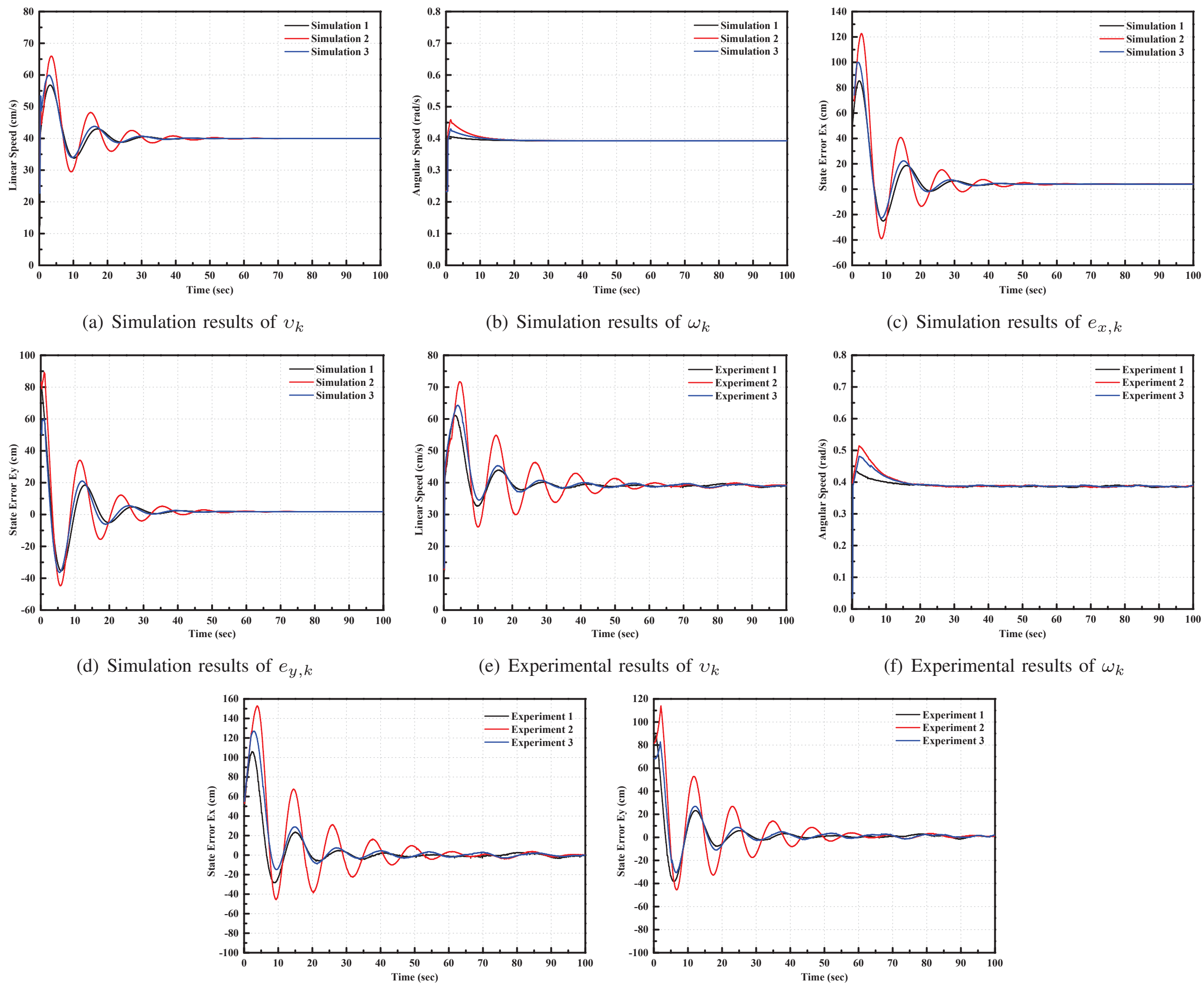


Fig. 3. Experimental platform of mobile robot

The reference trajectory to be tracked is a circular line which satisfies the kinematics model of the mobile robot (1) and having the following form

$$\begin{cases} x_k = x_{rc} + rsin\theta_k \\ y_k = y_{rc} - rcos\theta_k \end{cases}$$

the reference circular line is centered at $(x_{rc}, y_{rc}) = (0, 80)[cm]$ with radius $r = 100cm$. Other parameters are given as $\upsilon_{r,k} = 39.27cm/s$, $\omega_{r,k} = 0.393rad/s$, $k_x = 0.24$, $k_y = 0.36$, $k_\theta = 0.2$, with sampling period $T = 0.1s$.



(a) Simulation results of v_k

(b) Simulation results of ω_k

(c) Simulation results of $e_{x,k}$

(d) Simulation results of $e_{y,k}$

(e) Experimental results of v_k

(f) Experimental results of ω_k

(g) Experimental results of $e_{x,k}$

(h) Experimental results of $e_{y,k}$

Fig. 4. Simulation and experimental results with small time-delay

A. *Experimental platform*

In general, the experimental platform designed in this paper, as shown in Fig. 3, consists of four parts: Networked controller, Wireless router, Vicon system and Mobile robot.

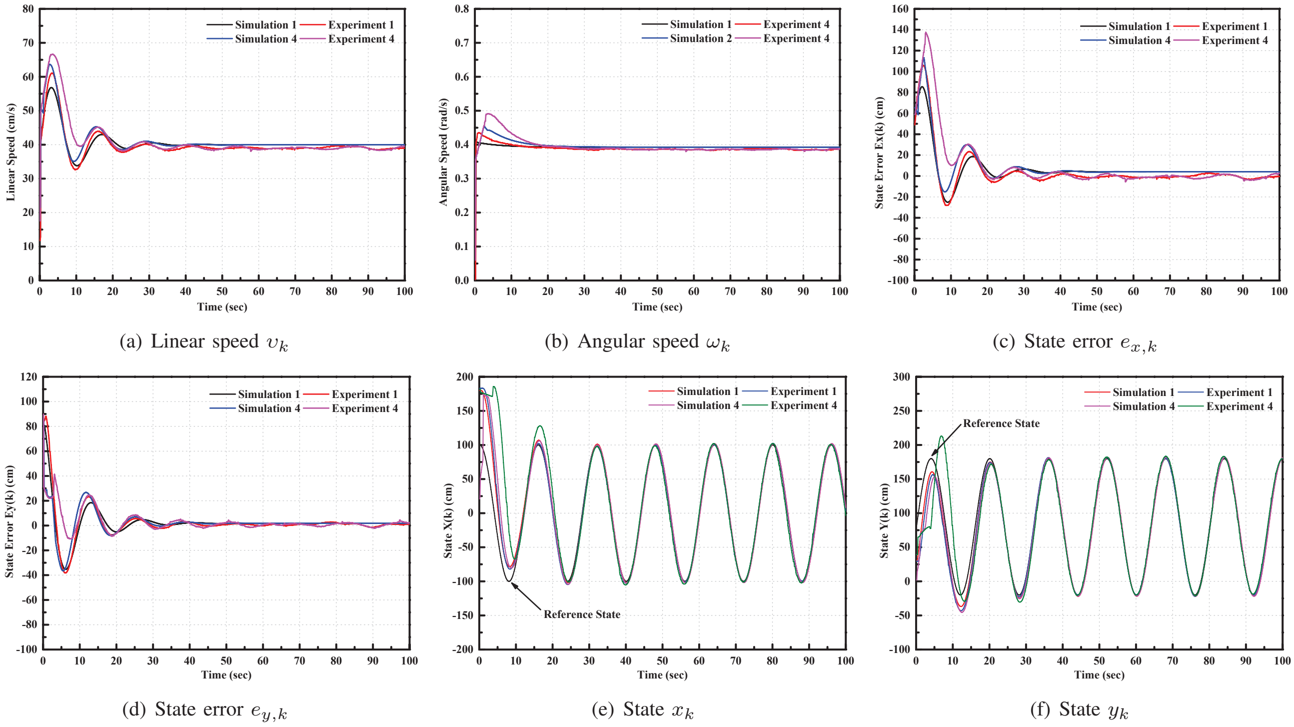
The Networked controller is designed and developmented by authors of this paper. It is capable of executing executable files that are derived from simulink block in Matlab/Simulink, and it build a bridge between theoretical research and engineering practice. The hardware resources of the Networked controller include two channel analog to digital converter, two channel digital to analog converter, two channel digital input, two channel digital output and three channel Pulse Width Modulation. Moreover, the Networked controller could communicate with PC and/or other Networked controllers using network send and receive modules using UDP protocol.

The mobile robot used in this paper is equipped with two driven wheels, and the wheel is individually actuated by stepping motor. An omni-directional wheel is placed at the back to keep balance. There is an additional Networked controller, which plays the role of receiving control inputs, embedded within the mobile robot.

There are four Vicon markers placed on mobile robot, which can be captured by Vicon cameras at each sampling period. After that, the positional information of mobile robot is obtained in Vicon system, and this positional information will be send to the Networked controller through wireless router. Based on the positional information of mobile robot and the reference states, control inputs of mobile robot are calculated in the Networked controller and transmitted to mobile robot using wireless network. Thus, the closed-loop tracking control system of mobile robot is achieved.

B. *Small time-delay in bilateral communication channels*

In laboratory environment, the transmition of data packets were achieved by a wireless router, which used UDP protocol. The time-delay was usually small (less than 10ms), and was smaller than one sampling period. When studying the issue that time-delay is larger than a sampling period, an artificial



(a) Linear speed υ_k (b) Angular speed ω_k (c) State error $e_{x,k}$

(d) State error $e_{y,k}$ (e) State x_k (f) State y_k

Fig. 5. Simulation and experimental results with large time-delay

delay function should be implemented. In this paper, the delay function block in Simulink Library Browse is adopted, which can be used in simulation research and can also be downloaded into the networked controller.

Further more, during the simulation study, the execution time of each individual block was synchronized since PC clock was used. Whereas for the experimental part, it is assumed that the execution time of each individual parts were synchronized (due to the time-delay exists in the communication channel being smaller than one sampling period). In other words, the time-delays in bilateral communication channels were introduced on the controller side artificially, thus allowing us to realize a network-induced delay both in simulation and experiment.

In this subsection, small time-delays, for $\tau_f = \tau_b = 5$, exist in the forward and feedback communication channels. The simulation and experimental results are shown in Fig. 4, where simulation 1 and experiment 1 are the case that none time-delays exist in the communication channels, and simulation 2/3 and experiment 2/3 are the results that τ_f and τ_b exist in the communication channels while using tracking controller (4) and (8), respectively. It can be seen that, when time-delays exist in the control loop, the control performance of controller (8) is better than that of (4), and the resluts are consistent with that of simulation 1/experiment 1. The tracking errors are bounded within $\pm 4cm$ finally.

C. Large time-delay in bilateral communication channels

When the time-delays exist in the communication channels are large enough, for $\tau_f = 12$ and $\tau_b = 10$, tracking controller (4) cannot satisfy the control performance requirements anymore, as shown in Fig. 6. Whereas, when using controller (8), the negative effects caused by time-delays are compensated actively, see Fig. 5, where simulation 4 and experiment 4 are the results using controller (8) under large time-delays.

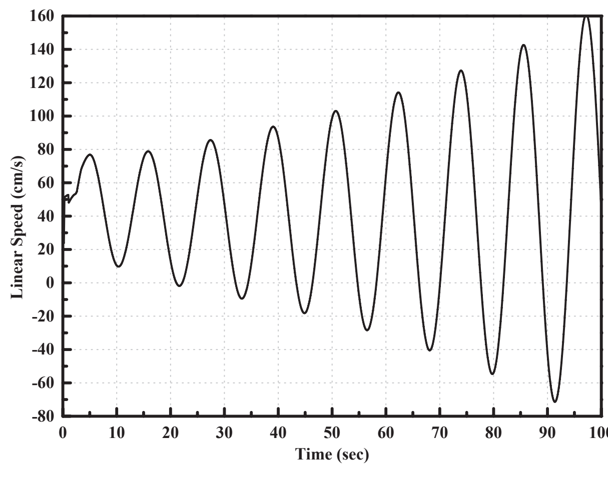
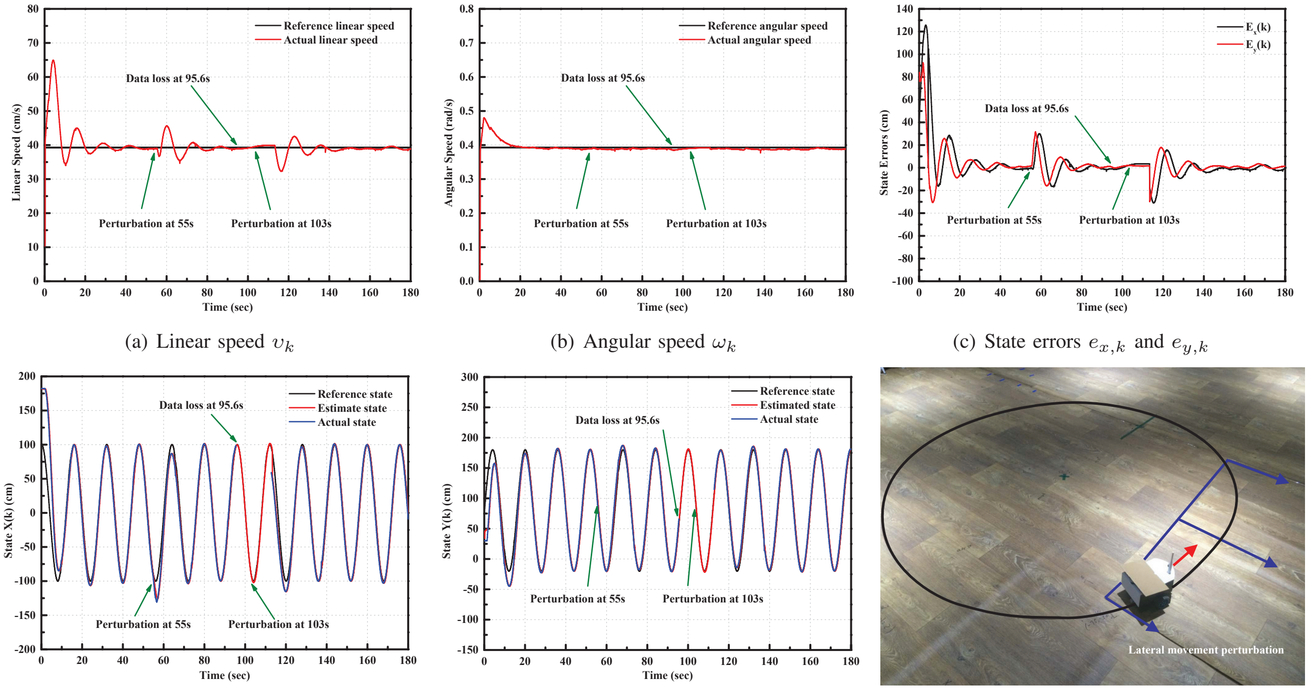


Fig. 6. Linear speed of mobile robot under large time-delay

Obviously, the moving trajectory of mobile robot finally converge to the reference states, with tracking errors bounded within $\pm 5cm$. Consequently, the network-induced delay in bilateral communication channels can be compensated actively.

D. Consecutive data losses in the feedback channel

When the wireless network is introduced into the control loop of mobile robot, the data packets losses are inevitable due



(a) Linear speed v_k (b) Angular speed ω_k (c) State errors $e_{x,k}$ and $e_{y,k}$

(d) State x_k (e) State y_k (f) Lateral movement perturbation when data lost in the feedback channel

Fig. 7. Experimental results with consecutive data loss in the feedback channel

to signal strength and network congestion in wireless router.

Generally speaking, in a real application of mobile robot, data packet drops will happen in two cases. Case 1: The time-delay in the communication channel exceeds the upper bound τ_{max}. Then, the data packet is considered to be lost. Case 2: If the sensor fails for a finite time period, the state of the mobile robot will never be transmitted to the controller, in which case it is also consider that the data packet is lost.

In both the above cases, the state of the mobile robot is regarded as lost on the controller side. To cope with this problem, the estimated state $\hat{q}(k|k-\tau_b)$ is adopted as $q(k)$. Thus, the issue of data packets lost can be solved.

To simulate data loss and to make the experiment more interesting, the Vicon markers are covered and perturbations are joined in the experimental process. When the Vicon markers are covered (sensor fails), Vicon system cannot acquire any information about the mobile robot, then a NAN response is sent to networked controller. Hence, the data packets in feedback channel are lost.

The experimental results are shown in Fig. 7. Obvious that the linear and angular speed of mobile robot converge to the reference speed (see Fig. 7(a) , Fig. 7(b)), and the moving trajectory converge to the reference states within $50s$ (see Fig. 7(d), Fig. 7(e)). At time $55s$, a lateral movement perturbation is joined, which could be found clearly in Fig. 7(c). When perturbation is joined into the moving trajectory of mobile robot, state errors $e_x(k)$ and $e_y(k)$ increase rapidly, which led directly to the linear speed changes in Fig. 7(a). The adjustment time is about $35s$ when the perturbation is eliminated. From time $95.6s$ to $111.8s$, the Vicon markers are covered, then the positional information is lost in the controller side. Moreover, another lateral movement perturbation is joined at time $103s$. It can be seen that the trajectories of linear/angular speed, positional states and state errors move smoothly until the cover on Vicon markers is removed at time $111.8s$, and which will finally converge to the references within $38s$, and the ultimate state errors are bounded within $\pm 4cm$.

Based on above results, it can be concluded that the networked predictive tracking controller (8) is capable of compensating consecutive data losses in the feedback channel. Whereas, if a perturbation occurs when the data packets are lost, controller (8) could not eliminate the perturbation immediately until networked controller received the positional information of mobile robot.

In addition, the data loss problem in forward communication channel can be solved by sending a control sequence $[\hat{u}_{k+\tau_f}, \hat{u}_{k+\tau_f+1}, \ldots, \hat{u}_{k+\tau_f+\tau_c}]$ from networker controller to mobile robot at stepping time k, where τ_c means the maximum number of consecutive packet loss. If the data packets from stepping time $k+1$ to $k+\tau_c$ are lost, then control sequence $\hat{u}_{k+\tau_f+1}, \ldots, \hat{u}_{k+\tau_f+\tau_c}$ at mobile robot side are used, and which are sent by networker controller at stepping time k. Objectively speaking, this approach will increase the burden on the network, as the size of data packet is greater than that of single data $\hat{u}_{k+\tau_f}$.

V. Conclusions

In this paper, the remote tracking control problem of a network-based Agent was considered, which subjected to network-induced bilateral time-delays. The overshoot of system increased as the network delay gone up, but the moving trajectory would finally converged to the reference states if these time-delays were small. Whereas, when time-delays were big enough, the moving trajectory could not converged to the reference states. To solve these problems, a networked predictive tracking control scheme was proposed, and which was capable of compensating the bilateral time-delays actively. Simulation results were clearly verified by experiments, which demonstrates the effectiveness of the proposed scheme. Moreover, consecutive data losses in the feedback channel could be compensated actively based on above approach, and it could be obviously seen when lateral movement perturbations were joined.

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